A Proposal to the Office of Naval Research
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for

# Solar Spectral Flux, Optical Depth, and Water Vapor Measurements and Analyses in the Puerto Rico Dust Experiment (PRIDE)

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Research Period and Budget Requested from ONR:

| | Task 1 | Task 2 | Total |
|---|---|---|---|
| June 1, 2000 - May 30, 2001: | $50.25K | $86.45K | $136.7K |

Reviewed by:

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Warren J. Gore, Chief Date
Atmospheric Physics Research Branch

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## ABSTRACT


We propose to provide measurements and analyses of solar spectral fluxes and direct beam transmissions in support of the Puerto Rico Dust Experiment (PRIDE). Spectral fluxes (300-1700 nm at 10 nm resolution) will be measured by a zenith and nadir viewing Solar Spectral Flux Radiometer (SSFR) on the SPAWAR Navajo and a zenith viewing ground-based SSFR. Direct beam transmissions will be measured in 6 narrow bands (380-1020 nm) by the 6-channel Ames Airborne Tracking Sunphotometer (AATS-6) on the SPAWAR Navajo; they will be analyzed to derive aerosol and thin-cloud optical depth at 5 wavelengths, plus column water vapor overburden. The data will be used to determine the net solar radiative forcing of dust (and other) aerosol, to quantify the solar spectral radiative energy budget in the presence of elevated aerosol loading, to support satellite algorithm validation, and to provide tests of closure with in situ measurements.


## 1 BACKGROUND

### 1.1 The Puerto Rico Dust Experiment (PRIDE)

The Puerto Rico Dust Experiment (PRIDE) is a field study of the radiative, microphysical, and transport properties of Saharan dust, scheduled for July 2000 (Reid, 2000). A group of Navy, NASA, and university scientists plan to conduct a combined surface, airborne, satellite and modeling campaign out of the Roosevelt Roads Naval Base, Puerto Rico in an effort to measure the properties of African dust transported into the Caribbean. There will be two principal thrusts: 1) Determine the extent to which the properties of dust particles and the spectral surface reflectance of the ocean surface need to be known before remote sensing systems can accurately determine optical depth and flux. 2) Evaluate/validate the skill in which the Naval Research Laboratory’s Aerosol Analysis and Prediction System (NAAPS) predicts the long-range transport and vertical distribution of African dust. The results of these efforts will support Navy and NASA applied science objectives on satellite validation and the prediction of dust-induced visibility degradation. In addition, secondary thrusts of PRIDE will address in situ issues of coarse mode particles and basic research issues on climate forcing, geochemical cycles, and meteorology.

## 1.2 Results From Previous Work

### 1.2.1 Solar Spectral Flux Radiometer (SSFR) Analysis and Results

*Cloud Remote Sensing*

The SSFR is a newer version of a prototype spectroradiometer that was first designed to infer the thermodynamic phase of clouds (Pilewskie and Twomey, 1987; Pilewskie and Twomey, 1992). Using measurements of either spectral reflectance or spectral transmission (defined by the observer's viewing angle; for reflectance, $\pi/2\leq\mu\leq\pi$; for transmission, $0\leq\mu\leq\pi/2$), cloud phase can be determined by the signal in the atmospheric window between 1.55 μm and 1.75 μm. Since ice is nearly four times more absorbing than liquid water at 1.65 μm, ice spectra have lower amplitude signal in this band. The ice spectrum also shows a shift of the peak signal towards longer wavelength when compared to a water cloud spectrum, following the absorption spectra of bulk liquid water and ice.

The result of applying asymptotic formulae to derive relationships between measured transmission and the bulk absorption affords a simple yet powerful constraint on the composition of absorbing material. These relationships can be used not only to unambiguously discriminate between cloud phase, but also to reveal the presence of a heretofore "unknown" absorber. Our observations of near-infrared cloud transmission have substantiated the premise that liquid water and ice are the dominant absorbers in the near-infrared window bands. Similar relationships are being employed to develop methods of inferring cloud ice/liquid water content and enhanced water vapor path through the multiple scattering medium of thick clouds (Pilewskie and Twomey, 1996).

*Clear Sky Solar Radiative Energy Budget*

The first SSFR data to be extensively analyzed and compared to model derived spectra for cloud-free conditions were obtained during the NASA SUCCESS experiment in 1995. Comparisons between measurements and model calculations of the spectrally resolved downwelling irradiance at the ground showed that for cloud-free conditions there was agreement to within instrumental and model uncertainties of 5% (Pilewskie, et al., 1998). The greatest disagreement occurred in the 400 -700 nm band. The integrated irradiance over the band from 400 nm to 2200 nm agreed to within 3%. Roughly 85% of the difference between the modeled and measured integrated irradiance occurred in the 400 to 700 nm band. The level of agreement between measured and modeled spectra in the water vapor absorption bands was encouraging, considering that water vapor is the primary absorber in the atmosphere. However, we concluded that it would be necessary to compare similar spectral data over a broader range of atmospheric conditions to fully assess our ability to model solar spectral irradiance.

Data acquired during the 1997 Department of Energy Atmospheric Radiation Measurement (DOE ARM) Shortwave Intensive Operating Period (SWIOP) shows that a discrepancy exists between models and observations in the cloud free atmosphere and it is highly correlated with water vapor (Pilewskie et al., 2000). The difference between modeled and measured flux increases most rapidly in the two mid-visible bands between 442 nm and 778 nm and the trend becomes nearly flat in the near-infrared (see Figure 1). Over this entire spectral region the difference grows at a rate of approximately 9 $Wm^{-2}$ per cm of water. Relative to the energy at the top of the atmosphere, the bias increases by about 1% per cm of water in the two bands between 442 and 625 nm and 625 and 778 nm, with smaller relative contributions in the other bands. The source of the discrepancy remains undetermined because of the complex dependencies of other variables on water vapor.

*Principal Component Analysis*

A formal approach to any remote sensing problem is to transform the original set of measured variables into a smaller set of mutually-orthogonal uncorrelated variables. For SSFR spectra, the measurement variables are irradiance (or radiance) values at many wavelengths. While several hundred measurements comprise a single spectrum, relatively few are independent: measurement of flux at one wavelength is sufficient to calculate flux in other regions of the spectrum given constituents of known absorption and scattering. The initial step is to determine the correlation between irradiance at different wavelengths which is then used to derive the *principal components*, linear combinations of the original irradiance values. The virtue of this procedure is to define the minimum number of parameters necessary to characterize atmospheric spectral irradiance, or the *dimensionality* of atmospheric variability. PCA can be applied to set limits on the number of parameters that can be inverted from a spectral data set.

Physically independent influences (in our application, different absorbers and scatterers: condensed water, oxygen, ozone, carbon dioxide, aerosols, etc.) do not in general produce independent orthogonal components in the measurement (spectral) domain. PCA produces orthogonal patterns, which of necessity are weighted combinations of the contributions of two or more independent influences. That difficulty faces PCA in general and has been discussed at some depth by Richman (1986), who describes so-called rotation schemes that affect a recombination of raw orthogonal patterns to produce patterns (non-orthogonal) that better separate effects of physically independent causes.

This was the general procedure followed by Rabbette and Pilewskie (2000) in the analysis of SSFR spectra from the ARM 1997 Fall Shortwave Intensive Observation Period (SWIOP). The input variable matrix used in that study constituted nearly 7000 spectra (between 360 and 1000 nm) which were acquired over a three-week period at the ARM CART site in north central Oklahoma. The time series of the first two rotated Principal Components (PCs) reveal strong similarities to the time series of cloud liquid water content (97% of the explained variance) and integrated column water vapor (2.5% of explained variance). Since the analyzed spectra were in the shortest wavelength region of the solar spectrum, variability associated with cloud water was due to scattering, not absorption.

*The Solar Radiative Energy Budget in the Cloudy Atmosphere*

The solar radiative energy budget of cloud the cloudy atmosphere has been the focus of considerable attention due to several recent studies which suggested that our ability to estimate broadband radiative fluxes and, consequently, to infer atmospheric absorption, using detailed radiative transfer models is poor (Cess, et al., 1995; Pilewskie and Valero, 1995; Valero et al., 1998). The recently completed Atmospheric Radiation Measurement (Arm) Enhanced Shortwave Experiment (ARESE) was the second major DOE field campaign dedicated to measuring the absorption of solar radiation by clouds. Figure 2 is an example of SSFR spectra during ARESEII and is representative of the type of data we will obtain during the PRIDE flight missions. During ARESEII the SSFR was integrated on the Sandia National Laboratory Twin Otter in nadir and zenith viewing ports. The blue curve is the nadir-viewing (upwelling) irradiance over north-central Oklahoma on 20 March 2000 at 1700 GMT. Spectral integration time is 100 ms. The red curve is the zenith-viewing (downwelling) irradiance, also at 1700 GMT, and the green spectrum is the difference between downwelling and upwelling irradiance, or the net flux. During ARESE II nearly 200,000 irradiance spectra were acquired over a variety of scenes and altitudes in the lower and middle troposphere.

### 1.2.2 Ames Airborne Tracking Sunphotometer (AATS) Analysis and Results

The Ames Airborne Tracking Sunphotometers (AATS-6 and AATS-14) have previously flown on a variety of aircraft to study a wide range of aerosol and trace gas phenomena. Among the AATS results most relevant to PRIDE are those obtained in the second Aerosol Characterization Experiment (ACE-2), where elevated layers of Sahara dust were studied over the eastern Atlantic Ocean (Russell and Heintzenberg, 2000). Figure 3 shows an example measured by AATS-14 on the Pelican aircraft in the Canary Islands (Schmid et al., 2000). The optical depth profiles in the left panel were smoothed and vertically differentiated to obtain the extinction profiles in the right panel. The extinction profiles clearly show the presence of three distinct layers: an elevated layer of Sahara dust, a moderately polluted marine boundary layer, and an intervening layer that is nearly aerosol-free. Note the marked difference in extinction wavelength-dependence in the two aerosol layers: a strong dependence in the boundary layer (extinction profiles separated in wavelength) and almost no dependence in the elevated dust layer (extinction profiles overlapping except at 1558 nm). This difference reflects the difference of aerosol size in the two layers, with accumulation-mode particles important in the polluted boundary layer and coarse-mode particles more important in the Sahara layer.

Figure 4 shows how the presence of elevated dust layers can affect the accuracy of optical depths retrieved from satellite radiance measurements. The scatter diagram in Figure 4a (Durkee et al., 2000) compares

AVHRR-retrieved aerosol optical depth (AOD) at 630 and 860 nm with AOD measured in ACE-2 by a variety of sunphotometers on land, ship, and aircraft. Data points with AOD>0.25 are cases where an elevated layer of Sahara dust was present; those with AOD<0.25 had no Sahara dust. For all 23 cases shown the AVHRR standard error of estimate is 0.025 for 630 nm wavelength and 0.023 for 860 nm. Note that in the dust-containing cases (AOD>0.25), the AVHRR-retrieved AODs are biased low compared to sunphotometer optical depths (by amounts ranging from 0.01 to 0.08). In contrast, for the dust-free cases AVHRR-retrieved values are biased slightly high. Figure 4b compares AOD spectra for a case from Figure 4a where dust was present (this is also the case from Figure 3); Figure 4c is the analogous comparison for a dust-free case (Livingston et al., 2000; Schmid et al., 2000). These cases show clearly the change in bias of the AVHRR retrieved values between dust-free and dust-containing cases, especially at 860 nm. Possible reasons for this change include differences between the wavelength-dependent single scattering albedos and phase functions of the Sahara dust and those assumed in the AVHRR retrieval (Durkee et al., 2000), plus the height of the absorbing dust aerosols (e.g., Quijano et al., 1999). In PRIDE, sunphotometer underflights of aerosols in different conditions (e.g., marine aerosols with and without Sahara dust aloft) could provide analogous tests of the validity of satellite products as a function of condition. Vertical profile flights by the sunphotometer aircraft or a coordinated aircraft could provide simultaneous in situ data on aerosol physicochemical properties, helping to complete the picture.

In addition to vertical profile flights, airborne sunphotometer measurements flown along horizontal transects near the land or ocean surface can provide aerosol optical depth spectra useful for validating products from simultaneous satellite overflights. This is illustrated in Figure 5, which shows a comparison of airborne sunphotometer (AATS-6), AVHRR, and ATSR-2 data acquired in TARFOX (Russell et al., 1999a) over the Atlantic Ocean when the UW C-131A flew across a gradient of aerosol optical depth between latitudes 37-39 N (Veefkind et al., 1999). The flight path was chosen using half-hourly GOES images to locate the aerosol gradient. Comparing Figures 5a and 5b shows that the ATSR-2 retrieval reproduces the sunphotometer-measured optical depth gradient better than the AVHRR retrieval. Comparing 3c and 3d shows how the ATSR-2 retrieval also matches the sunphotometer-determined Angstrom exponent better than AVHRR. In PRIDE, GOES or other realtime satellite imagery could be used to design flight legs across the gradient from plume core to edge during a subsequent satellite overpass (by, e.g., EOS Terra carrying MODIS, MISR, and CERES). AATS optical depth spectra on legs flown near the surface would provide validation data for comparisons such as those in Figure 5.

Figure 6 shows other comparisons from TARFOX, when AATS-6 on the UW C-131A underflew the MODIS Airborne Simulator (MAS) on the NASA ER-2 (Tanre et al., 1999). These comparisons focus on the wavelength dependence of optical depth and illustrate how the magnitude of optical depth affects the success of the MAS retrieval. Specifically, the good agreement in wavelength dependence and magnitude obtained when optical depth is relatively large (>0.2 for $\lambda$<1 $\mu$m) degraded when optical depth decreased below ~0.05 (causing MAS-measured radiance from the aerosol to decrease relative to radiance from the ocean surface). Establishing such limits and uncertainties is a major reason for validation studies. In PRIDE they could be conducted for a variety of aerosol types and conditions, over different types of land surfaces (e.g., densely vs. sparsely vegetated), glint-free and glinting swaths of ocean, and on transects spanning land and ocean.

# 2 PROPOSED RESEARCH

## 2.1 Objectives

The objectives of the proposed research are to:

(1) Improve understanding of dust, other aerosol, and water vapor effects on radiative transfer, radiation budgets and climate in the Caribbean region, and
(2) Test and improve the ability of satellite remote sensors (such as MODIS, MISR, CERES, TOMS, AVHRR) to measure these constituents and their radiative effects.

## 2.2 Proposed Tasks

### 2.2.1 ONR-Funded Task One: SSFR Measurements and Analyses

The NASA Ames Radiation group will deploy a Solar Spectral Flux Radiometer (SSFR) on the SPAWAR Navajo during the Puerto Rico Dust Experiment (PRIDE) in June-July, 2000. The SSFR has zenith and nadir viewing light collectors for measuring solar spectral upwelling and downwelling irradiance from 300 to 1700 nm at 10 nm resolution. This data will be used to determine the net solar radiative forcing of dust (and other) aerosol, to quantify the solar spectral radiative energy budget in the presence of elevated aerosol loading, and to support satellite algorithm validation. We will attempt to deploy a zenith viewing ground-based SSFR (for no additional cost to the project) at a selected surface site.

The SSFR is calibrated for wavelength, absolute power, and angular response at the NASA Ames Research Center. Some of this work is done in conjunction with the Ames Airborne Sensors Facility which takes part in round robin calibration comparisons with NIST and the University of Arizona. The Airborne Sensors Facility is also responsible for calibrating flight simulation sensors, such as the MODIS Airborne Simulator (MAS), and the use of identical standards will allow us to trace SSFR calibrations to MAS.

We will meet all data archival schedules; we anticipate three levels of data release.

### 2.2.2 ONR-Funded Task Two: AATS-6 Measurements and Analyses

For the funding requested in this proposal (Section 3) the NASA Ames Sunphotometer/Satellite group will perform the following subtasks: (a) Integrate the 6-channel Ames Airborne Tracking Sunphotometer (AATS-6) on the SPAWAR Navajo. (b) Calibrate AATS-6 before and after PRIDE. (c) Provide continuous realtime measurements of aerosol and thin cloud optical depth spectra and water vapor column contents during PRIDE flights. (d) Use these data in flight direction and planning.

### 2.2.3 NASA-Funded Integrated Analyses

In addition to ONR funded Tasks One and Two, we plan to perform the following subtasks using NASA funding: (e) Compare AATS-6 results to those of the satellite sensors listed above (as, e.g., in Figures 4-6); in cases of disagreement, investigate causes and retrieval algorithm improvements. (f) For aircraft profiles derive profiles of aerosol extinction spectra and water vapor density by differentiating optical depth and column water vapor profiles (as exemplified by Figures 3 and 7). (g) Combine these data with those from the SSFR and conduct new analyses of aerosol radiative forcing sensitivity, single scattering albedo, and the solar spectral radiative energy budget (as exemplified by Figure 8). (h) Derive aerosol size distributions from optical depth and extinction spectra (as exemplified by Figure 9). (i) Combine data with in situ measurements (e.g., the SPAWAR measurements of size distribution, scattering, and/or absorption) to provide tests of closure and integrated assessments of aerosol and trace gas radiative effects. An example of such a closure test is shown in Figure 10 (Schmid et al., 2000). Results of the analyses will be reported in joint publications with collaborating investigators.

## 2.3 Schedule

6/00: Integration of SSFR and AATS-6 on SPAWAR Navajo
6/00: Final pre-flight SSFR and AATS-6 calibration
6-7/00: Field deployment
8-10/00: post-flight calibrations
11/00: first data release
3/01: second data release
6/01: final data release

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## 3. BUDGET*

This budget covers field measurements (including calibrations), preparation, and basic data reduction. Integrated analyses and publications are not included; these will be covered by NASA budgets or, when appropriate, by a separate budget request to ONR.

| | ONR-Funded Task 1, SSFR | | ONR-Funded Task 2, AATS | |
|---|---|---|---|---|
| Contract/Chargeback | 19.98 | 1a | 51.08 | 2a |
| Supplies, Parts | 16.92 | 1b | 3.50 | 2b |
| Travel | 6.69 | 1c | 22.05 | 2c |
| Shipping | 2.82 | | 3.20 | |
| Documentation Support | 1.00 | | 1.73 | |
| NASA Reimbursable Taxes (6%) | 2.84 | | 4.89 | |
| Total | 50.25 | | 86.45 | |

Notes:

1a. Programmer, 0.25 WY @ $79.9K/WY

1b. Primarily spare detector arrays, optical domes, and fiber optic bundles.

1c. Includes post-experiment calibration trip to JPL Table Mountain Solar Observatory

2a. J. Livingston, 0.20 WY @ $188K/WY; B. Schmid, 0.07 WY @ $104K/WY; J. Redemann, 0.04 WY @ $88K/WY; Programmer, 0.04 WY @ $67K/WY.

2b. Includes digitizer parts, A/C interface, electronics, tools.

2c. Includes pre- and post-experiment calibration trips to Mauna Loa Observatory (Civil servants and contractors).

*NASA is currently reviewing and changing its budget and accounting procedures to accommodate a full-cost management model. It is likely that for FY 2001 and beyond all budget requests will have to be amended or modified to reflect this new management approach. When we receive further guidance on the revised procedures, a revised budget for those affected years will be submitted.

## 4. STAFFING, RESPONSIBILITIES, AND VITAE

Drs. Peter Pilewskie and Philip B. Russell will be Co-Principal Investigators. Dr. Pilewskie will be responsible for the SSFR measurements and analyses; Dr. Russell will be responsible for the AATS-6 measurements and analyses. Drs. Pilewskie and Russell will collaborate on analyses that combine SSFR and AATS-6 measurements, as well as on flight planning for such measurements. They will be responsible for the completion of their tasks within budget and schedule. Mr. John Livingston will have primary responsibility for AATS-6 calibrations and airborne measurements. He and Dr. Beat Schmid will participate in AATS-6 preparation, data analyses, and publications. Dr. Jens Redemann will participate in selected calibrations and analyses. Ames will furnish additional engineering and technical personnel necessary to maintain, operate, and repair the instrumentation before, during, and after the calibrations and field measurements.

## (a) Peter Pilewskie
## Abbreviated Curriculum Vitae

**Education:**
B.S., Meteorology, Pennsylvania State University, 1983
M.S., Atmospheric Science, University of Arizona, 1986
Ph.D., Atmospheric Science, University of Arizona, 1989

**Professional Experience:**
Radiation Group Leader, Atmospheric Physics Branch, NASA Ames Research Center, 1994-present
Research Scientist, Atmospheric Physics Branch, NASA Ames Research Center, 1989-1994
Research Assistant, Institute of Atmospheric Physics, University of Arizona, 1983-1989

**Professional Activities:**
Member, Atmospheric Radiation Measurement (ARM) Enhanced Shortwave Experiment (ARESE) II Science Team
Member, Solar Radiation and Climate Experiment (SORCE), 1999-present
Member, Triana Science Team, 1998-present
Member, Global Aerosol Climatology Program (GACP), 1998-present
Member, Atmospheric Radiation Measurement Program (ARM) Science Team, 1997-present
Member, International Global Atmospheric Chemistry (IGAC), Focus on Atmospheric Aerosols, Direct Aerosol Radiative Forcing Activity, 1995-present
Member, First International Satellite Cloud Climatology Program (ISCCP) Regional Experiment, Phase III (FIRE III) Science Team, 1994-present
Science Team Leader, International Global Aerosol Program (IGAP), Radiative Effects of Aerosols, 1993

**Professional Honors:**
NASA Exceptional Scientific Achievement Medal, 1997
NASA Group Achievement Award, FIRE Phase II Science and Operations Team, 1997
NASA Ames Honor Award, Scientist, 1995

**Selected Publications:**
Pilewskie, P., M. Rabbette, R. Bergstrom, J. Marquez, B. Schmid, and P.B. Russell, The discrepancy between measured and modeled downwelling solar irradiance at the ground: Dependence on water vapor. *Geophys. Res. Lett.* **25**, 137(2000).
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Pilewskie, P. and S. Twomey, Discrimination of ice from water in clouds by optical remote sensing. *Atmos. Research*, **21**, 113 (1987).

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## (b) Philip B. Russell
## Abbreviated Curriculum Vitae

B.A., Physics, Wesleyan University (1965, Magna cum Laude; Highest Honors). M.S. and Ph.D., Physics, Stanford University (1967 and 1971, Atomic Energy Commission Fellow). M.S., Management, Stanford University (1990, NASA Sloan Fellow).

Postdoctoral Appointee, National Center for Atmospheric Research (1971-72, at University of Chicago and NCAR). Physicist to Senior Physicist, Atmospheric Science Center, SRI International (1972-82). Chief, Atmospheric Experiments Branch (1982-89), Acting Chief and Acting Deputy Chief, Earth System Science Division (1988-89), Chief, Atmospheric Chemistry and Dynamics Branch (1989-95), Research Scientist (1995-present), NASA Ames Research Center.

Currently, Member, Science Team for Global Aerosol Climatology Project (GACP; Investigation Title: Improved Exploitation of Field Data Sets to Address Aerosol Radiative-Climatic Effects and Development of a Global Aerosol Climatology). Member, Science Teams for SAGE II and SAGE III (satellite sensors of stratospheric aerosols, ozone, nitrogen dioxide, and water vapor). Primary responsibilities: analyses of volcanic aerosol properties and effects, development of the SAGE III Aerosol Algorithm Theoretical Basis Document (ATBD), and experiment design and data analyses to validate the satellite measurements.

Previously, NASA Ames Associate Fellow (1995-96, awarded for excellence in atmospheric research).

Previously, Co-coordinator for the CLEARCOLUMN component of the Second Aerosol Characterization Experiment (ACE-2) of the International Global Atmospheric Chemistry (IGAC) Project. Coordinator for IGAC's Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX). Convenor of TARFOX Special Sessions, Spring 1997 Meeting, American Geophysical Union (AGU). Coordinator, TARFOX special issues of *Journal of Geophysical Research* (1998-99). Program Co-Chair, International Specialty Conference on Visual Air Quality, Aerosols, and the Global Radiation Balance (Bartlett, New Hampshire, 10/1997). Member, Direct Aerosol Radiative Forcing Committee of IGAC Focus 8: Atmospheric Aerosols (1996-98).

Previously, Editor (1993, 1996) and Editor-in-Chief (1994-95), *Geophysical Research Letters*; Member, Board of Editors and Atmospheric Science Executive Committee, American Geophysical Union. Guest Editor, *Journal of Geophysical Research* Special Issues on "Midlatitude Stratospheric Dynamics and Cross-Tropopause Exchange," "Tropical Stratosphere-Troposphere Exchange," and "SAGE II Aerosol and Ozone Data Validation and Initial Data Use" (1988-93). Convenor, Sessions on the Atmospheric Effects of 1991 Pinatubo Eruption, AGU Fall Meeting (1992). Organizer and/or report editor, Workshops on "Requirements for a Very-High-Altitude Aircraft for Atmospheric Research," "Scientific Application of Remotely Piloted Aircraft Measurements of Radiation, Water Vapor, and Trace

Gases to Climate Studies," and "Mission Measurement Strategies for the Subsonic Assessment Program" (1989-94). Member, Interagency Task Group on Airborne Geoscience (1987-89), Member, American Institute of Aeronautics and Astronautics (AIAA) Losey Atmospheric Sciences Award Selection Committee, (1986-87), Member, AIAA Atmospheric Environment Technical Committee (1984-90), Invited Participant, World Meteorological Organization Experts Meeting on Aerosols and their Climatic Effects (1983), Invited Participant, NOAA Workshop on Global Large Aerosols (1982), Chair, American Meteorological Society International Committee on Laser Atmospheric Studies (1979-82, Member, 1978-82), Member, National Research Council Committee on Army Basic Research (1979-81), Member, American Meteorological Society Committee on Radiation Energy (1979-81).

Previously, Project Scientist, Small High-Altitude Science Aircraft (SHASA) Project to develop the Perseus A Remotely Piloted Aircraft (RPA, 1992-94), Member, Science/Aeronautics Seam Team of NASA Ames Reorganization Team (1994), Member, Ad Hoc Committee on the NASA Environmental Research Aircraft and Sensor Technology (ERAST) Program (1993-4), Member, NASA Red Team on Remote Sensing and Environmental Monitoring of Planet Earth (1992-3), Leader, NASA Ames Earth Science Advanced Aircraft (ESAA) Team (1990-94), Member, National Aero-Space Plane (NASP) Committee on Natural Environment (1988-94), Member, NASA Ames Strategy and Tactics Committee (1986-87), Chair, NASA Ames Atmospheric Science Strategy Review Team (1986-87), Manager, NASA Stratosphere-Troposphere Exchange Project (STEP, 1983-93), Member, NASA Solar-Terrestrial Observatory Science Study Group (1979-80), Member, NASA Atmospheric Lidar Working Group (1977-79) , Member, NASA Spacelab 2 Investigations Review Panel (1977).

NASA Exceptional Service Medal (1988, for managing Stratosphere-Troposphere Exchange Project), NASA Space Act Award (1989, for invention of Airborne Autotracking Sunphotometer), and NASA Group Achievement Awards (1994, for Stratospheric Photochemistry, Aerosols and Dynamics Expedition; 1991, for Airborne Arctic Stratospheric Expedition; and 1989, for Airborne Antarctic Ozone Experiment). Graham Prize (1965, outstanding undergraduate in natural science, Wesleyan University). Member, Phi Beta Kappa and Sigma Xi.

Patent, "Airborne Tracking Sunphotometer Apparatus and System" ( U.S. Pat. No. 4,710,618, awarded 1987)

## SELECTED PUBLICATIONS


**2000:**

Collins, D. R., et al. (with P. B. Russell), In situ aerosol size distributions and clear column radiative closure during ACE-2. *Tellus B*, in press, 2000.

Durkee, P. A., et al. (with P. B. Russell), Regional aerosol properties from satellite observation: ACE-1, TARFOX and ACE-2 results. *Tellus B*, in press, 2000.

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[See 2 *Tellus B* papers led by Livingston and Schmid in their CVs.]

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**1999:**

Bergstrom, R. W., and P. B. Russell, Estimation of aerosol radiative effects over the mid-latitude North Atlantic region from satellite and in situ measurements. *Geophys. Res. Lett., 26*, 1731-1734, 1999.

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**1998:**

Boucher, O. et al. (with P. B. Russell), Intercomparison of models representing direct shortwave radiative forcing by sulfate aerosols, *J. Geophys. Res.*, *103*, 16,979-16,998, 1998.

[6 2-page peer-reviewed extended abstracts in *J. Aerosol. Sci.* describing TARFOX and ACE-2 results.]

**1997:**

Hamill, P., E. J. Jensen, P. B. Russell, and J. J. Bauman, "The Life Cycle of Stratospheric Aerosol Particles", *Bull. Am. Meteor. Soc.*, *78*, 1395-1410, 1997.

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Russell, P. B., S. Kinne and R. Bergstrom, "Aerosol Climate Effects: Local Radiative Forcing and Column Closure Experiments," *J. Geophys. Res., 102*, 9397-9407, 1997.

**Five Other Relevant Papers:**

Russell, P. B., J. M. Livingston, R. F. Pueschel, J. J. Bauman, J. B. Pollack, S. L. Brooks, P. Hamill, L. W. Thomason, L. L. Stowe, T. Deshler, E. G. Dutton, and R. W. Bergstrom. "Global to Microscale Evolution of the Pinatubo Volcanic Aerosol, Derived from Diverse Measurements and Analyses." *J. Geophys. Res., 101*, 18,745-18,763, 1996.

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Russell, P.B., J.M. Livingston, and E.E. Uthe. "Aerosol-Induced Albedo Change: Measurement and Modeling of an Incident." *J. Atmos. Sci., 36*, 1587-1608, 1979.

## (c) John Livingston
## Abbreviated Curriculum Vitae

Senior Research Meteorologist, Applied Physical Sciences Laboratory,
SRI International, Menlo Park, CA 94025

### Specialized Professional Competence

Atmospheric physics and meteorology; atmospheric radiometry; computer simulation of atmospheric remote sensing systems; numerical analysis and inversion of in-situ and remotely sensed atmospheric data

### Representative Research Assignments at SRI (Since 1978)

Acquisition and analysis of ground-based, airborne, and shipboard sunphotometer measurements
Validation of satellite particulate extinction measurements (SAM II, SAGE I, and SAGE II), and corresponding studies of the global distribution of stratospheric aerosols
Analysis of *in situ* measurements of stratospheric and tropospheric aerosols
Acquisition, modeling and analysis of Differential Absorption Lidar measurements of tropospheric ozone
Simulation of passive sensor radiance measurements to infer range to an absorbing gas
Experimental study of aerosol effects on solar radiation using remote sensors
Error analysis and simulation of lidar aerosol measurements
Analysis of lidar propagation through fog, military smoke, and dust clouds
Evaluation of the lidar opacity method for enforcement of stationary source emission standards
Weather forecasting for large-scale air pollution field study
Testing and evaluation of an offshore coastal dispersion computer model
Application of objective wind field and trajectory models to meteorological measurements

### Professional Experience

Research Meteorologist to Senior Research Meteorologist, SRI International (1978-present)
Research assistant, University of Arizona Institute of Atmospheric Physics (1974-1977)
NASA Kennedy Space Center (1975-1976): participant in thunderstorm electrification studies

## Academic Background

University of Notre Dame Year-in-Japan Program (1971-1972), Sophia University, Tokyo, Japan
B.S. summa cum laude in earth sciences (1974), University of Notre Dame, Notre Dame, IN
M.S. in atmospheric sciences (1977), University of Arizona, Tucson, AZ
M.B.A. with highest honors (1992), Santa Clara University, Santa Clara, CA

## Honors

NASA Ames Research Center Contractor of the Year (1997), NASA Certificate of Recognition (1992) for co-authored technical paper, NASA Group Achievement Award (1989) for Airborne Antarctic Ozone Experiment

## Professional Associations

American Geophysical Union

## PUBLICATIONS


**2000:**

Collins, D. R., et al. (with J. M. Livingston), In situ aerosol size distributions and clear column radiative closure during ACE-2. *Tellus B*, in press, 2000.

Durkee, P. A., et al. (with J. M. Livingston), Regional aerosol properties from satellite observation: ACE-1, TARFOX and ACE-2 results. *Tellus B*, in press, 2000.

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Welton, E. J., et al. (with J. M. Livingston), Ground-based lidar measurements of aerosols during ACE-2: Instrument description, results, and comparisons with other ground-based and airborne measurements. *Tellus B*, in press, 2000.

**1999:**

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Schmid, B., J. Michalsky, R. Halthore, M. Beauharnois, L. Harrison, J. Livingston, P.. Russell, B. Holben, T. Eck, and A. Smirnov, Comparison of aerosol optical depth from four solar radiometers during the Fall 1997 ARM Intensive Observation Period, *Geophys. Res. Lett*., *104*, 2261-2278, 1999.

**1998:**

[6 2-page peer-reviewed extended abstracts in *J. Aerosol. Sci.* describing TARFOX and ACE-2 results.]

**1997:**

Hegg, D. A., J. Livingston, P. V. Hobbs, T. Novakov, and P. B. Russell, Chemical Apportionment of Aerosol Column Optical Depth Off the Mid-Atlantic Coast of the United States. *J. Geophys. Res. , 102* , 25,293-25,303, 1997.

**Five Other Relevant Papers:**

Livingston, J.M., and P. B. Russell, Retrieval of aerosol size distribution moments from multiwavelength particulate extinction measurements. *J. Geophys. Res., 94*, 8425-8433, 1989.

Pueschel, R.F., J. M. Livingston, G. V. Ferry, and T. E. DeFelice, Aerosol abundances and optical characteristics in the Pacific basin free troposphere. *Atmos. Envir., 28,* 951-960, 1993.

Pueschel, R.F., J. M. Livingston, P. B. Russell, and S. Verma, Physical and optical properties of the Pinatubo volcanic aerosol: aircraft

observations with impactors and a Sun-tracking photometer. *J. Geophys. Res.*, *99*, 12,915-12,922, 1994.
Russell, P. B., J. M. Livingston, R. F. Pueschel, J. J. Bauman, J. B. Pollack, S. L. Brooks, P. Hamill, L. W. Thomason, L. L. Stowe, T. Deshler, E. G. Dutton, and R. W. Bergstrom, Global to Microscale Evolution of the Pinatubo Volcanic Aerosol, Derived from Diverse Measurements and Analyses. *J. Geophys. Res.*, *101*, 18,745-18,763, 1996.
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## (d) Beat Schmid
## Abbreviated Curriculum Vitae

Bay Area Environmental Research Institute
3430 Noriega Street
San Francisco, CA 94122

### Education

| | | |
|---|---|---|
| M.S. (Lizentiat) | 1991 | Institute of Applied Physics, University of Bern, Switzerland |
| Ph.D. | 1995 | Institute of Applied Physics, University of Bern, Switzerland |
| Postdoctoral Fellowship | 1995-97 | Institute of Applied Physics, University of Bern, Switzerland |

### Professional Experience

Bay Area Environmental Research Institute, San Francisco, CA (1997-Present)
-Senior Research Scientist
University of Arizona, Tucson, AZ (Oct. 1995 -Jan. 1996)
-Visiting Scientist
University of Bern, Switzerland (1989-1997)
-Research Assistant (1989-1995)
-Postdoctoral Researcher (1995-1997)

### Scientific Contributions

- 7 years of leading studies in ground-based and airborne sun photometry: instrument design and calibration, development and validation of algorithms to retrieve aerosol optical depth and size distribution, $H_2O$ and $O_3$.
- Participate with the NASA Ames Airborne Sun photometers in ACE-2 (North Atlantic Regional Aerosol Characterization Experiment, 1997, Tenerife). Extensive comparison of results (closure studies) with other techniques: lidar, optical particle counters, nephelometers, and satellites.
- Participate with the NASA Ames Airborne Sun photometers in the Dep. of Energy, Atmospheric Radiation Measurement (ARM) program integrated fall 1997 intensive observation period (IOP) in Oklahoma. Appointed to lead sun photometer intercomparison. Extensive comparison of water vapor results with radiosondes, microwave radiometers, lidar, and Global Positioning System.
- Test of candidate methods for SAGE 3 satellite ozone/aerosol separation using airborne sunphotometer data.
- Application of NOAA/AVHRR satellite data to monitor vegetation growth in Switzerland

### Scientific Societies/Committees

-American Geophysical Union
-American Meteorological Society

### Publications

**2000:**

**Schmid, B.,** J. M. Livingston, P. B. Russell, P. A. Durkee, H. H. Jonsson, D. R. Collins, R. C. Flagan, J. H. Seinfeld, S. Gassó, D. A. Hegg, E. Öström, K. J. Noone, E. J. Welton, K. J. Voss, H. R. Gordon, P. Formenti, and M. O. Andreae, Clear sky closure studies of lower tropospheric aerosol and water vapor during ACE-2 using airborne sunphotometer, airborne in-situ, space-borne, and ground-based measurements, Tellus, in press, 2000.
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**1999:**

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### PROFESSIONAL EXPERIENCE

**Research Scientist** — April 1999 to present
Bay Area Environmental Research Institute, San Francisco.

**Research Assistant** — May 1995 to March 1999
University of California, Los Angeles, Department of Atmospheric Sciences.

**Lecturer** — Jan. 1999 to March 1999
University of California, Los Angeles, Department of Atmospheric Sciences.

**Tutor** — 1997 to 1998
Ivy West Educational Services, Marina Del Rey, CA.

**Research Assistant** — June 1994 to April 1995
Free University of Berlin, Germany. Department of Physics.

### EDUCATION

**Ph.D. in Atmospheric Sciences.** — 1999
University of California, Los Angeles. Specialization: atmospheric physics and chemistry.

**M.S. in Atmospheric Sciences.** — 1997
University of California, Los Angeles. Specialization: atmospheric physics and chemistry.

**M.S. in Physics.** — 1995
Free University of Berlin, Germany. Specialization in experimental physics and mathematics.

### RELEVANT RESEARCH EXPERIENCE

- Developed inversion algorithms (C and IDL) and data analysis tools for aircraft-based lidar and sunphotometer measurements during field experiments (PEM, TARFOX).

- Compared remotely sensed data to aerosol in situ measurements and devised techniques to retrieve the vertical structure of aerosol optical properties and radiative effects.
- Involved in the development of a multi-wavelength, ground-based lidar system at the Free University of Berlin, Germany.
- Provided solutions to scientific and numerical problems pertaining to aerosol physics and performed validation measurements relevant to Clean Room Technology for the computer chip industry.
- Specialized course work in atmospheric sciences, geophysical fluid dynamics, cloud physics, radiative transfer and remote sensing.

## HONORS

| | |
|---|---|
| Invited Speaker at the Atmospheric Chemistry Colloquium for Emerging Senior Scientists (ACCESS V). | June 1999 |
| Outstanding Student Paper Award, American Geophysical Union - fall meeting. | 1998 |
| NASA Global Change Research Fellowship Awards. | 1996-1998 |
| UCLA Neiburger Award for excellence in the teaching of the atmospheric sciences. | 1997 |

## ORGANIZATIONS

American Association for Aerosol Research, American Geophysical Union, Co-president of the UCLA - Atmospheric Sciences Graduate Student Group.

## RELEVANT PUBLICATIONS


**2000:**

Redemann, J., R.P. Turco, K.N. Liou, P.B. Russell, R.W. Bergstrom, B. Schmid, J.M. Livingston, P.V. Hobbs, S. Ismail, E.V. Browell. Retrieving the Vertical Structure of the Effective Aerosol Complex Index of Refraction From Aerosol In Situ and Remote Sensing Methods During TARFOX, *J. Geophys. Res.*, in press.

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